AOSN MURI: Utility Acoustic Modem and Robust Communications

Mark Johnson
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
Phone: 508-289-2605
Fax: 508-457-2195
Email: majohnson@whoi.edu
Award: N00014-95-1-1316

LONG-TERM GOALS

To create and demonstrate a reactive survey system, capable of long-term unattended deployments in harsh environments. We refer to such a system as an Autonomous Ocean Sampling Network (AOSN). The goal of the Utility Acoustic Modem effort is to develop a low-power hardware platform and a robust signaling strategy for data communications between components such as robotic vehicles, moorings, or ocean-bottom assets, in an AOSN.

OBJECTIVES

To develop and evaluate a complete hardware and software solution for acoustic communications between vehicles and moorings in an AOSN system. Emphasis is on the reliability of the communications link in the face of vehicle self-noise, other active systems (e.g., navigation), and rapidly changing multi-path. To this end, we are developing a suite of signaling techniques, covering a wide range of data-rates and coding strategies, together with a means for selecting the optimal method on a packet-by-packet basis. This will lead to a responsive system, capable of high data-rate in good channels and some data transfer even in very poor channels.

APPROACH

Effort this year has focussed on implementing and evaluating signaling strategies for real-time acoustic communications using the Utility Acoustic Modem (UAM) platform developed in 1997. The UAM is a high performance, low power, digital signal processing modem which can be programmed with essentially any communications strategy. Work this year has therefore been in algorithm and software development for the UAM. The touchstones for acoustic communications system design for the AOSN are:

1) Autonomy -- the modems will, most often, be remote and so must be capable of unsupervised operation.
2) On-line -- all receptions must be decoded on the modem in reasonable time to provide a real-time data link.
3) Robustness to high level transients. These are mostly from acoustic systems associated with autonomous underwater vehicles such as long base-line (LBL) navigation, Trackpoint ultra-short base-line (USBL) navigation, and dock homing signals.
4) Robustness to substantial and strongly time-varying multipath as occurs with a moving source or receiver in shallow water.

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **1998**	2. REPORT TYPE	3. DATES COVERED **00-00-1998 to 00-00-1998**

4. TITLE AND SUBTITLE **AOSN MURI: Utility Acoustic Modem and Robust Communications**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Woods Hole Oceanographic Institution,Woods Hole,MA,02453**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002252.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Given these constraints, relatively low data rates were targeted. This is consistent with the need for a high reliability communications link for control and compressed or 'quick-look' data in an AOSN. Higher data-rates and modulation-agile methods will be the focus of the following year of the program.

Preisig and Brady (WHOI and Northeastern University) have developed several signaling strategies and receiver algorithms meeting the above criteria. These have been evaluated using theoretical results and simulated channels in MATLAB. The signals have also been transmitted in a number of shallow water locations around the coast of Massachusetts in order to collect real channel data. A complete set of communications functions, based on this signals and algorithms has been implemented by Johnson and Brady on the UAM.

The UAM was a central component in two major experiments in 1998: the Labrador Sea AOSN in January-February, and the Cape Cod Bay AOSN in September. In these experiments, UAMs were used for unsupervised data and control communications between vehicles, moorings, and the ship, but were also used for USBL homing for the vehicle, and for off-line acoustic communications link evaluation and data collection.

WORK COMPLETED

Two classes of robust signaling techniques have been evaluated this year: frequency-hopping FSK (frequency shift keying), and sequence position modulation. Frequency-hopping FSK is a spread-spectrum technique used widely in difficult or power-limited RF channels. A major advantage of the method in underwater communications is that very little environmental information is required to design and decode the signal making it well-suited to unsupervised modem operation. In fact, a prior upper bounds on the multipath spread and inter-platform velocity are the only environment-dependent design figures. The accuracy of these figures determines the system data-rate and error-rate in an intuitively straightforward way.

A complete transmitter and receiver using frequency-hopping FSK has been implemented on the UAM and has been evaluated in at-sea trials throughout the year. An early version of the system was used in the Labrador Sea AOSN in January/February to provide uni-directional status and data communications from an Odyssey vehicle to the dock mooring and a shipboard UAM. The shipboard system displayed mission progress and real-time CTD data. In order to ensure reliable operation in the harsh conditions and largely unknown acoustics of the Labrador Sea, a very conservative 100 bps (bits-per-second) FSK signal was chosen. Although much higher data rates may have worked, the link, as designed, was extremely reliable and operated without supervision for the entire deployment. Most importantly, it was quite immune to interference from other active systems in the experiment. Range of the system was, however, limited to about 1 mile.

Following the Labrador Sea experiment, a number of enhancements were made to the UAM and frequency-hopping strategy. Chief amongst these were:

(i) improvements to the power amplifier to approximately double the output power.
(ii) implementation of a new high performance detect sequence to use as a preamble to acoustic packets. This was needed to extend the range of acoustic communications without increasing the false detection of other active systems.
(iii) implementation of a strong error-correction code with interleaving to allow recovery from long burst errors.

These enhancements were made not only to extend the range of the acoustic link but also to improve robustness to the level needed for receiving at an AUV (autonomous underwater vehicle) while underway. A number of tests were performed in Woods Hole harbor to debug and evaluate the enhanced system and a considerable data set has been obtained.

The enhanced UAM communications system was used in the Cape Cod Bay AOSN in September. In this experiment, a total of 6 UAMs were used on moorings, AUVs and aboard ship. The low-cost moorings, designed by Keith von der Heydt under a parallel program, each consist of a UAM with an RF serial modem allowing remote control and re-configuration of the UAM. The moorings act as bridges between the RF and acoustic communications channels and so form the centerpiece of a remotely-supervised AOSN. To allow acoustic communications reception at the AUV, a shock-mounted hydrophone was designed and installed for the Cape Cod Bay experiment. The hydrophone was mounted in the nose of the vehicle and was mechanically isolated from structure-borne thruster noise.

The other robust communication method evaluated this year by Brady is sequence position modulation (SPM), a generalization of pulse position modulation. In SPM, information is coded in the interarrival times between adjacent pulses. A round-robin selection from a list of preferred maximal length sequences (m-sequences) is used for transmission pulses. Adjacent pulses may be modulated by the same carrier, or by different carriers. Due to the low cross-correlation between the preferred m-sequences, SPM allows pulses to be spaced much closer than the delay spread of the multipath channel. Due to the thumbtack shape auto-correlation function of each preferred m-sequence, the temporal resolution afforded by correlation detection is usually better than a chip period. This autocorrelation function also permits the resolution of two paths separated by 3/8 m, at a chip rate of 4kHz.

As with pulse position modulation, SPM is not a spectrally efficient method of communication. However, it is a very attractive method of modulation for low-power transmitters for two reasons:

1) the transmitter duty cycle can be made quite low (information is transmitted by the duration of silence between pulses), and
2) the active transmit power may be attenuated by the processing gain of the m-sequences.

SPM is an ideal modulation method for command and control information to a receiver on-board a noisy vehicle, or for surf-zone communication between autonomous vehicles. A shallow water experiment was conducted during the third week of September to gather real-channel data for evaluating the method.

RESULTS

The frequency-hopping FSK communication strategy was operated on UAMs at both the Labrador Sea and Cape Cod Bay AOSN deployments. The frequency range in both experiments was in the 10-20kHz range. At the Labrador Sea AOSN, extremely reliable communications from an AUV to the dock mooring were achieved at a range up to 1.5km. The dock UAM operated without supervision and forwarded receptions via satellite to a remote shore station. Vehicle transmissions were also received at the ship allowing sensor data to be displayed during missions. Messages from the vehicle contained its position, mission time, and CTD measurement. Fig. 1 shows an example vehicle

run with the positions at which messages were received at the dock indicated by colored balls. A total of 723 messages were decoded by the dock UAM, representing 14.5kbytes of data. The estimated error rate was 0.0006 with approximately 50% of errors occurring when the vehicle was within 1m of the surface, a situation with notoriously poor acoustics. Decoding performance did not deteriorate greatly at the maximum range indicating that packets were simply not detected rather than undecodeable. This motivated the development of the hop code detector featured in the Cape Cod Bay AOSN.

Using the enhanced UAM communications system, considerably improved results were obtained in the Cape Cod Bay AOSN. We achieved reliable communication at 10km range (the maximum range attempted) between the shipboard UAM and a buoy. The data rate was 200bps and very few errors were obtained due to the strong error correction code and use of interleaving. Reliable communication was obtained from the AUV to a buoy at 5km range, the shorter range resulting from the use of a lower output transducer on the AUV. Bi-directional acoustic communication was obtained between the ship and the AUV at 4km range. An acoustic control link was established to the AUV computer and we were able to command the vehicle to change course or execute a yo-yo sampling maneuver and then receive confirmation acoustically.

Because of the severely stratified temperature profile in Cape Cod Bay in late summer, the received signal strength was extremely sensitivity to the depth of the hydrophones and transducer in the water column. Signal level fluctuations of over 20 dB were seen with changes in vertical position of just one or two meters. Although the communications link operated over a wide dynamic range, the observation highlights the importance of considering acoustic channel conditions when configuring a communications system. Work is continuing to evaluate data from the Cape Cod Bay deployment as well as to improve the data-rate of the UAM communications system.

For the SPM communications strategy, in-water data collecting experiments were performed in September. SPM packets were transmitted over a 300m range with an average water depth of 1m near the shoreline of Nahant, MA. Six m-sequences were selected, each consisting of 127 chips. The chip rate was 4kHz, and the common carrier frequency was 35kHz. The transmission path was collinear and through the breaker line, in order to test the performance of the detection technique in the extreme surf-zone. Passband data was sampled, stored and processed offline. Many configurations were considered, for example, an SPM packet at a data rate of 475 bits per second, with a transmit duty cycle of 10%. This packet was demodulated without the use of coding, and only 1 error was experienced in over 1000 bits. Current work is focused on an efficient error-correcting coding strategy for SPM in a dynamic multipath channel. Since the temporal error time series is a correlated process, error codes are being considered which exploit this correlation and reduce the residual error variance.

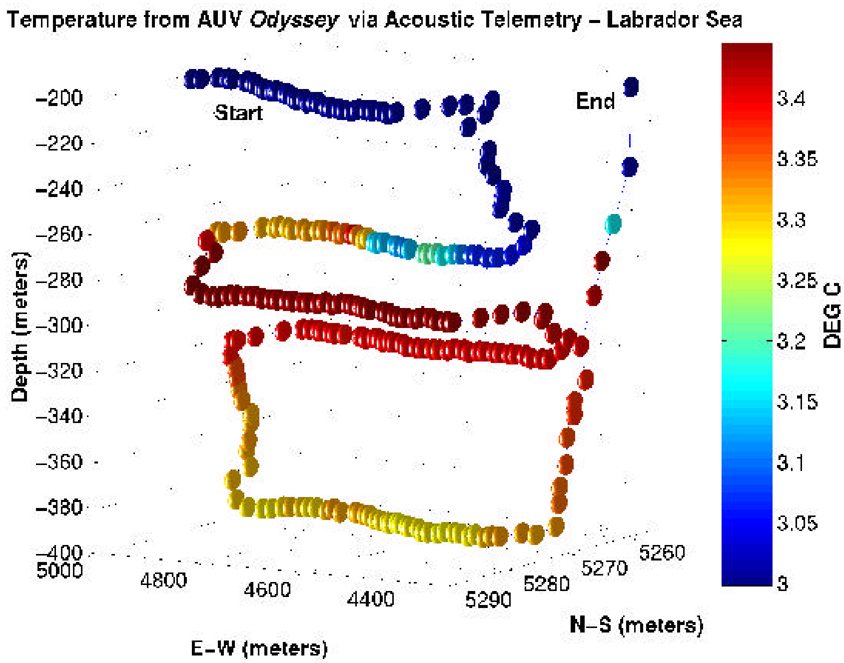

Figure 1

IMPACT/APPLICATIONS

The UAM communications capability developed under the MURI has broad potential not only in other AOSN applications but also in the wider ocean research and commercial domains. To this end, discussions continued this year with representatives of several ocean instrumentation manufacturers to identify a suitable technology transfer partner. A total of 30 UAMs will be completed by the end of 1998, funded under a related DURIP, and many of these will be available for loan to other researchers via the WHOI Acoustic Modem Pool. We believe that the ready availability of reliable acoustic communications equipment will enable a variety of ocean experiments and make possible interactive survey and measurement systems.

TRANSITIONS

A number of funded and to-be funded projects will use UAM hardware and communications technology developed under the MURI. These include the following:

<u>MURI-AOSN</u>:

The aim of this program is to develop techniques and technology to interactively observe an ocean volume with high resolution in space and time. Both fixed and mobile measurement platforms are being developed. The roles of the UAM are:

(i) to provide data and control communication between platforms (including moorings and autonomous underwater vehicles) during measurement missions, and
(ii) to provide bearing information for homing a vehicle to an acoustic beacon on an underwater dock.

NOPP Low Cost Telemetry:

Under this program we will develop a moored platform with a UAM to receive data acoustically from instruments (for example, velocimeters) in the water volume adjacent to the mooring. Such instruments will use a miniaturized, reduced-function version of the UAM, designed under the NOPP. The miniature modem will be very low-cost and suitable for retrofit in many common underwater instruments.

ULTRAMOOR (NSF):

The goal of this program is to develop a moderate cost, deep water instrumented mooring for long-term (5 year) deployment. To avoid the cost and vulnerability of a multi-conductor electrical/mechanical cable, the mooring will use the UAM and miniature modem combination developed under the NOPP 3D Flow Measurement (WHOI internally funded): An array of UAMs will be used to track current-following drifters. Each drifter will contain an expendable acoustic transmitter which periodically broadcasts a pressure measurement along with a unique identification number.

RELATED PROJECTS

This project is part of the Multidisciplinary University Research Initiative: "Real-Time Oceanography with Autonomous Ocean Sampling Networks: A Center for Excellence".

PUBLICATIONS

[1] Frye, D., Johnson M., von der Heydt K., "A Moored System for Data Telemetry and Control of Autonomous Underwater Vehicles," Ocean Community Conference '98 (MTS), Baltimore, November, 1998.

[2] Johnson, M., Stojanovic, M., and Freitag, L., "Improved Doppler tracking and correction for underwater acoustic communications," ICASSP '97, Munich, April, 1997.

[3] Freitag, L., Johnson, M., and Stojanovic, M., "Efficient equalizer update algorithms for acoustic communication channels of varying complexity," Proceedings Oceans '97, Halifax, September, 1997.